Study on A. Tonomura's Experiment of Bi-prism of Electron Beam

By

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Abstract

In this article, we study A. Tonomura's experiment of bi-prism of electron beam. Thereby, we verify the two facts that an electron is a particle and that the observation of the natural statistical phenomena is the sampling of the natural random variable defined on a certain physical system.

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In this article, we study A. Tonomura's experiment of bi-prism of electron beam. Thereby we intend to solve the two problems in the following.

One problem is to verify that **"an electron is a particle".**

One another problem is to answer the question "what is the observation of a natural statistical phenomenon".

As the conclusions, we verify that an electron is a particle and clarify that the observation of a natural statistical phenomenon is the **sampling** of a natural random variable defined on the physical system.

At first we study the verification that the electron is a particle.

In 2012, Akira Tonomura died leaving the memorandum that "an electron is a wave" is my life. Many physicists are working in order to answer the question which is an electron, a wave or a particle. Professor Takabayashi had studied the “foundation of quantum mechanics”. He died leaving the solitary word he miss the “tamasii”.

I wish to dedicate my article to the mercy of the tamasii of many physicists died like this. I am writing this article praying for the souls of Doctor Tonomura and the many physicists as this,

In spite of Tonomura’s memorandum, I report that the fact “an electron is a particle” have been verified by unraveling Tonomura’s experiment of bi-prism of electron beam, and I report that we are now free from the preconceived idea of “standard interpretation” of “quantum mechanics”.

Among the experiments verifying the fact “an electron is a particle”, we show the following three experiments as the representatives.

1. Measurement of the electric charge e of an electron. （Oil-drop experiment of Millikan, 1911）.

2. Measurement of the mass m of an electron. (J. J. Thomson, 1897).

   By using the interactions of the cathode ray and the magnet and the interaction of the cathode ray and the electric field, J. J. Thomson determined the specific charge e/m.

3. Experiment of bi-prism of electron beam. (Akira Tonomura, 1989).

The fundamental factor of a physical particle is that the physical existence has its proper mass $m > 0$ and the proper electric charge $q, (-\infty < q < \infty)$.

The first and second experiments verify that the electron has the fundamental factor as the physical particle. Namely, the first experiment is the experiment which determined the electric charge e directly. The second experiment determined the specific charge e/m. Thereby it determined the mass of an electron m combined with the first experiment.

Until now , the third experiment is considered to be the experiment verifying the fact that “an electron is a wave”.

In this article, I wish to show that the third experiment is , in fact, completely opposite, namely that the this experiment verifies that an electron is a physical particle.

I show that the third experiment is the observation of the natural statistical phenomenon showed by the set of electrons.

Thereby, at the same time, we solve the question what is the observation of the natural statistical phenomenon.

Namely, because an electron is considered as a mass point, this electron moves by virtue of Newtonian equation of motion. As the natural statistical phenomenon showed by such a set of electrons, the natural statistical sample of the natural statistical distribution of the position variable of electrons is the meaning of the observed data of Tonomura’s experiment of bi-prism of electron beam.

Namely it is verified that an electron moves by virtue of Newtonian equation of motion as a mass point. By virtue of this verification experiment, it is established the fact that "an electron is a physical particle. It is established that "an electron is not a wave".

On the bases of Newton's laws of motion as the fundamental laws of the classical physics, we can understand and explain Tonomura's experiment as the natural statistical phenomenon of the set of electrons.

It is not the verified fact that "an electron is at the same time a particle and a wave" as it were said so until now because no one observe any electron which is a particle and a wave once at the same time.

An electron is always observed as a particle.

If we receive and consider this observed facts honestly, it is true that an electron is a particle. There is no other scientific evidence of the fact that an electron is a physical particle. There is no other method of the scientific verification of the fact that an electron is a physical particle.

Because the peoples had mistaken to read the mathematical information of the "wave function" in "quantum mechanics", the peoples got the wrong interpretation "an electron is a particle and a wave at the same time". Thereby the peoples had the curious explanation of the "quantum phenomena".

Although no body see an electron which is "a particle and a wave" at the same time, it becomes a standard expression that "an electron is a particle and a wave" at the same time without notice.

Then we cannot read the meaning of the obvious fact that an electron is observed as only a "particle" actually. The preconceived ideas of the peoples are such the things. As the holy Buddha said, the peoples cannot understand the things correctly since they are prepossessed with the preconceived ideas. If you see correctly and think correctly the real phase of the phenomenon without these preconceived ideas, you must correctly understand the meaning of the fact that an electron is observed only a particle.

The characteristic property of the natural statistical phenomena is that they are the statistical phenomena of these physical systems. We consider the following examples with respect to the differences between the motion of a physical particle as a single particle and the natural statistical phenomenon of the physical system as a family.

Now we consider Tonomura's experiment of bi-prism of electron beam.

Each electron moves by virtue of Newtonian equation of motion as a material point and is printed on the dry plate as a point. We overlap these photos ten thousand times. Then the distribution of ten thousand electrons are mapped there. This statistical distribution is seemed as the stripes of shade. This is the observed image of the natural statistical distribution of the statistical sample of the observation of the natural statistical phenomenon of the physical system. This is evidently different from the image of an electron being one particle as a point. This is just the statistical sample.

To overlap the ten thousand photos printed on the dry plate as a point for one electron is just to plot the statistical distribution of the statistical sample of the ten thousand data on the plane. This statistical distribution is determined by the L^2-density being the solution of Schrödinger equation as the natural statistical distribution.

This verifies that so to speak a "quantum phenomenon" is a natural statistical phenomenon.

Thereby, because the natural statistical phenomenon is such a statistical phenomenon, the observation of the natural statistical phenomenon is clarified to be the sampling of the statistical data.

The theoretical model of the experiment of bi-prism of electron beam is formulated as the double slit experiment.

Now we study the double slit experiment. As for the interference fringes of photons, Young's experiment is known. Nevertheless, the physical characteristics of photons are not yet well known. There is the fundamental problem which is the light, a particle or a wave.

Even though the dimension is different, we consider the double slit experiment in Ito [1], Figure 12.1.1 as the theoretical model.

This is the double slit exmeriment where electrons go through two slits from the left to the right, and reach to the screen at the right end and come to the rest. Then the stripes of shade appear. It is the problem that we understand and explain this phenomenon using the natural statistical physics.

As the theoretical model, we consider the model of the system of one particle which is composed of electrons moving under the potential $V(x)$ in the one dimensional space. We consider that the mass of an electron is m.

We postulate that the physical system is $\Omega = \Omega(\mathcal{B}, P)$.

We assume that the natural statistical state of the physical system at time t is determined by the L^2-density $\psi(x,t)$. This develops with time by virtue of Schrödinger equation

$$\begin{aligned}
&i\hbar\frac{\partial\psi(x,t)}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\psi(x,t)}{\partial x^2} + V(x)\psi(x,t),\\
&\psi(x,0) = \psi(x),\ \text{(I.C.)}\\
&(-\infty < x < \infty,\ 0 < t < \infty).
\end{aligned}$$

Here $\psi(x)$ is the initial condition. The choice of $\psi(x)$ is the essential point when we understand the double slit experiment.

Now assume that two slits are represented as two small intervals in the one dimensional space.

Let the physical subsystem composed of the set of electrons which go through the slit S_1 be Ω_1, and the physical subsystem composed of the set of electrons which go through the slit S_2 be Ω_2. Then the total physical system Ω has the direct decomposition such that

$$\Omega = \Omega_1 + \Omega_2.$$

Now, assume that the time when electrons go through the slit S_1 or S_2 is $t = 0$.

Then the distribution of the electrons which go through the slit S_1 is determined by the solution $\psi_1(x,t)$ of the Schrödinger equation for the initial condition $\psi_1(x)$ which is an L^2-density with its support in S_1, and the distribution of the electrons which go through the slit S_2 is determined by the solution $\psi_2(x,t)$ of the Schrödinger equation for the initial condition $\psi_2(x)$ which is an L^2-density with its support in S_2,

$\psi_1(x,t)$ determines the natural statistical distribution of the physical subsystem Ω_1, $\psi_2(x,t)$ determines the natural statistical distributions of the physical subsystem Ω_2.

Now, the initial distribution of the electrons of the physical system Ω is given by the relation

$$\psi(x) = \alpha\psi_1(x) + \beta\psi_2(x), (-\infty < x < \infty),$$

$$|\alpha|^2 + |\beta|^2 = 1,\ (\alpha, \beta \in \boldsymbol{C}).$$

Then the natural statistical distribution of the total physical system Ω at the time t is given by the L^2-density

$$\psi(x,t) = \alpha\psi_1(x,t) + \beta\psi_2(x,t).$$

This means that the natural statistical distribution of the total physical system Ω at the time t is determined as the composite state of the two physical subsystems Ω_1 and Ω_2.

Then, for a measurable set A in the one dimensional space, the probability that an electron is in A at the time t is given by the relation

$$\begin{aligned}\int_A |\psi(x,t)|^2 dx = |\alpha|^2 \int_A |\psi(x,t)|^2 dx + \overline{\alpha}\beta \int_A \overline{\psi_1(x,t)}\psi_2(x,t)dx \\ +\overline{\beta}\alpha \int_A \overline{\psi_2(x,t)}\psi_1(x,t)dx + |\beta|^2 \int_A |\psi_2(x,t)|^2 dx.\end{aligned}$$

Here the graph of the probability density

$$\begin{aligned}|\psi(x,t)|^2 = |\alpha|^2|\psi(x,t)|^2 + \overline{\alpha}\beta\overline{\psi_1(x,t)}\psi_2(x,t) \\ +\overline{\beta}\alpha\overline{\psi_2(x,t)}\psi_1(x,t) + |\beta|^2|\psi_2(x,t)|^2\end{aligned}$$

represents the natural statistical distribution state of the electrons as the the stripes of shade on the screen.

The graph of this probability distribution has the shape of wave and the stripes of shade is similar to the shape of the interference fringes of waves. Therefore the peoples interpret that an electron which is a particle exists expanding as a wave at the same time.

By the consideration in the above, we can conclude that this probability density gives only the mathematical information of the distribution state of the electrons and , therefore, it does not characterize the property of the electron as the physical existence.

Hence the expression "an electron is a particle and a wave at the same time" is known to be wrong.

Thereby, the fact "an electron is a particle" is verified.

The many curious discussions how electrons go through the two slits S_1 and S_2. It is important to consider the meaning of the double slit experiment on the bases of the observed results of the real double slit experiment.

If we observe the double slit experiment for the various conditions about the scales of the slits and the separation of two slits and the distance of the slits and the screen, we can determines the motion of electrons quantitatively.

If we try the numerical experiments conditioning the various numerical data, we can obtain the various informations on the motion of electrons.

References

[1] Y. Ito, *New Quantum Theory,* II, Science House, 2007.

[2] A. Tonomura, *Watch Quantum Mechanics. Challenge of Electron Holography,* Iwanami, 1995.